Art. IX.—*The Active Volcano on Tana, New Hebrides, with some remarks on the Cause of Volcanic Action.*

With Map and Plates 5, 6, 7 and 8.

By Frederick A. Campbell, C.E. (Melb.)

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Tana is one of the southern islands of the New Hebrides group, and lies approximately in 20° south latitude and 170° east longitude. It is about 30 miles long by 12 miles wide, and is densely covered with the most luxuriant tropical vegetation. The interior is occupied by a range of mountains which rises to a height of about 2500 feet, and so far as I know, has never yet been explored. The shores are partly fringed by a narrow coral reef, outside of which the water deepens rapidly, and good anchorage is difficult to find. There is only, or more correctly speaking was only until recently, one harbour on the island, viz., Port Resolution, a picturesque basin about one mile in diameter, situated upon the south-eastern side and opening towards the north.

Four-and-a-half miles to the north-west of this harbour, the active volcano Mount Yasur, is situated. It rises from a plain or wide flat valley which separates the elevated land of the Port Resolution district from the still more lofty ranges of the interior. A ridge 400 or 500 feet high extends from the harbour towards the volcanic cone, descending as it approaches that hill, the summit of which stands about 500 feet above the plain beyond and 700 feet above the sea level.

The volcanic district, that is the area over which are scattered traces of volcanic action, past and present, is about 20 square miles in extent, being a belt about $2\frac{1}{2}$ miles wide, extending from the sea coast outside and to the south of Port Resolution, for a distance of seven miles to the active cone of Mount Yasur.

Plate 5 gives a vertical section drawn through this part of the island. Plate 6 gives a plan of this district upon which I have marked the approximate position of the various volcanic phenomena.

Commencing at the most southerly, these may be briefly catalogued as follows :—

Hot springs on the outer sea coast.

A deposit of contorted ropy lava on the same coast about one mile farther north.

Hot springs on the south-east side of Port Resolution, temperature about 100°.

Hot springs on the west side of Port Resolution, temperature about 200°.

Stratified beds of a sort of argillaceous sandstone, closely allied to pumice stone, and used by sailors for holystoning the decks, alternated with this, bands of cinders or slag. These are seen in the cliffs on each side of the entrance to the harbour, where the sea has exposed a vertical section to view.

Hot beds of white clay occur further to the west. These are soft, when opened with a stick emit jets of sulphurous steam, and have a temperature ranging up to 200° Fah.

A small lake exists to the southward of this, the water of which has a temperature of about 100° Fah.

Beds of sulphur lie close to the active cone, as well as a large deposit of lava which stands piled up to a height of about 200 feet, the precipitous face of which indicates that it has issued forth in a very viscous state.

Just at the foot of the mount and beyond it, there lies a beautiful fresh water lake about one-and-a-half miles long by half-a-mile in width. It is fed by one of the largest streams in the island, it has no outlet to the sea, but disposes of its superfluous waters by pouring them continuously into large crevices on that edge which is next to the volcanic cone.

The cone itself is composed of loose scoriæ lying at an angle of about 2 to 1, with hardened lava protruding here and there, and blocks of a more porous nature strewn upon its surface.

The top of the cone is occupied by two distinct craters of about equal size and form, one, the farthest west being active, the other extinct. The active crater is an oval basin about 700 feet long, 500 feet wide, and 150 feet deep. Two large and one smaller vents occupy the bottom, the larger ones being about 50 feet in diameter; from these and from cracks in the sides of the crater, jets of steam continually rise, and the ground everywhere is almost too hot to touch. Between the eruptions, the crater is empty of lava, and there is nothing but the hissing steam jets to indicate the existence of the tremendous forces imprisoned below.

Plate 7 gives a general view of the volcano from the north-east, the entrance to Port Resolution being shown on the extreme left.

There are two other active volcanoes on this group, and another in the Santa Cruz Islands immediately to the north, particulars of which I have given in a paper recently read before the "Royal Geographical Society of Australasia," and entitled "Some Coral and Volcanic Islands of the Western Pacific."

Whilst Mount Yasur resembles these, in that it is subject to eruptions at times on a very large scale, it differs very materially from them in that, while they rise to about 3000 feet above sea level, it has an elevation of only about 700 feet, while their normal state is that of a steady emission of smoke without noise, that of Yasur is one of rapid and regular, but comparatively feeble, explosions.

The Eruptions of Mount Yasur.

In the paper previously referred to, I have given the fullest details obtainable from various sources upon this part of the subject; it will be necessary, however, to recapitulate the leading points, and for the sake of presenting the history of this volcano in the clearest form, I have arranged the various records in chronological order:—

1774.—Cook, and Forster.—This is the first record of the volcano. They remark that it threw up prodigious quantities of fire and smoke; that the explosions resembled claps of thunder, followed by a rumbling noise, and that showers of rain appeared to increase its violence. Hot springs and solfataras were observed by them on the west side of the harbour, and it was noticed that when the eruptions were violent, the quantity of steam emitted from these springs was considerably increased. The interval between the eruptions was observed to be about five minutes.

1793.—Labillardière observed it from a distance, and remarks that columns of smoke rose to a prodigious height, and after traversing a great space, sunk as they grew cooler.

1840.—Aneityum Native.—A very violent eruption occurred about this year.

1862.—Turner records the intervals between the eruptions as from six to eight minutes.

1865.—Brenchly notes the intervals as about the same as Turner, and observes that the eruptions were more violent than usual during the months of January, February and March.

1872.—Campbell.—When visiting the group at that time, I noted the period between eruptions as varying from four to six minutes, according to the state of the weather. In the winter, when the trade winds were blowing and the weather was fine, there would be hardly a minute of difference in the intervals for weeks together. So far as I recollect, there was no perceptible difference in the intervals during the day as compared with those during the night, that is, the temperature did not seem to affect the eruptions.

1873.—Markham notes the eruptions as occurring every three minutes.

10th January, 1878. Neilson.—A tremendous eruption took place, accompanied by an earthquake and an upheaval of the land. A fortnight afterwards, this was repeated on a smaller scale.

April 1888. Watt.—A violent eruption took place, accompanied by an earthquake, and further upheaval.

The eruptions of this volcano may be conveniently divided into three different classes :—1st., The normal or quiescent ; 2nd., the violent ; 3rd., the paroxysmal. I will trea of these in the order named :—

1st.—The Normal or Quiescent State.

The interval between the eruptions is on the average from four to five minutes. When particularly sluggish, the interval increases to as much as eight minutes. A longer time than this without eruptions has never been noticed, according to the Rev. Thos. Neilson, who was resident for 14 years at Port Resolution, and therefore is a competent authority on the subject.

The sound accompanying each eruption is a loud report, followed by a more continuous rumbling, almost exactly like that produced by the firing of a heavy piece of ordnance, and this is heard to a distance of about 30 miles. A sensible vibration of the sound is felt at Port Resolution with each explosion. The material ejected from the crater consists of red hot lava in the form of spherical bombs, large irregular fragments, in some cases as large as a horse, clouds of fine volcanic dust appearing as densely black smoke, and steam. The heavy fragments are thrown to a height of 500

or 600 feet above the crater, falling back into it again, or carried by the wind over the leeward edge. The clouds of steam and smoke generally assume a globular form, and carried away by the wind, distribute upon the space over which they pass quantities of fine volcanic dust.

Accompanied by Mr. Neilson, I visited the crater, and spent some time in watching the phenomena of its eruptions. It was difficult, however, under the circumstances to make calm and reliable observations. The noise was so appalling and the situation so unusual and exciting that one could well be pardoned for not collecting much accurate and reliable data. The eruptions were too close also to be studied properly, and the general impression received was of a simultaneous explosion, earth tremor, and projection high into the air of a torrent of stones, lava and smoke. Between these principal explosions however, molten lava occasionally surged up in the vents, accompanied by small explosions and the ejection of fragments to a short distance around, very much as is described as occurring at Stromboli in the Mediterranean. The different vents appeared also to exhibit a certain variety in their action, one of them throwing the lava higher and with a loud explosion, the other throwing up the larger masses with a less degree of force, as if they tapped the reservoirs beneath at points of different pressure.

2ND.—THE VIOLENT STATE.

At certain periods the volcano becomes more than usually active, the eruptions being not only more frequent, but more forcible. A greater quantity of material is ejected, and it is thrown to a greater height, much of it falling outside the crater, and rolling down the sides. Referring to this state Mr. Neilson writes:—"Its period diminishes sometimes to 45 or 50 seconds, and during rainy and thundry-looking weather, it will thud away for a fortnight or three weeks at this rate, shaking the whole island at every explosion and being heard to a distance of 50 or 60 miles away.

Mr. Forster, the companion of Captain Cook, more than a century ago, noticed that rainy weather increased the violence of the eruptions, and so did Mr. Brenchly in 1865. I observed that the rapidity and violence was increased not only when the weather grew sultry, and bad weather approached, but also during rain and for a short time after rain.

3rd.—The Paroxysmal State.

At irregular intervals of time, this volcano and district have been the scene of eruptions upon a scale of unusual violence. Traces of vast disturbances in the past are evident, and in historic times, there are records of three such occurrences, regarding which I have been able to collect the following particulars :—

1840 (Approximately).—Upon the authority of a native of Aneityum, a tremendous eruption took place on Tana about this time, and quantities of pumice stone floated across from Tana to Aneityum.

January 10th, 1878.—Very full details of this eruption have been furnished to me by Mr. Neilson, who was living then at Port Resolution. During the night of the 9th of January the wind had been blowing hard, and the morning broke very dark and lowering. About 9 o'clock a.m. the most severe shock of earthquake known since the islands were settled took place, lasting some four or five seconds. Simultaneously with this, the western side of Port Resolution was raised with an even tilting motion, and a large mass from the face of the cliffs near the entrance was hurled forward into the sea, causing a tremendous disturbance, and projecting a wave some 40 feet high against the land on the opposite side.

The eastern side of the harbour escaped almost entirely, only a few rocks being displaced, but the western side was raised to the extent of about 25 feet. The whole of the district between the harbour and the volcano was shaken and rent by fissures which occurred almost every 100 yards. Several natives fell into these, but were able to extricate themselves before being engulphed. For several weeks afterwards, this district emitted dense volumes of steam from these fissures, and the active cone of "Yasur" presented the appearance of having been partly shaken down, a flow of ashes having taken place westward and into the lake, partially encroaching upon it.

About a fortnight afterwards, another earthquake and eruption took place, with a second upheaval of the western side of Port Resolution to a height of seven feet more.

The volcano itself after about three weeks' display of tremendous eruptive force, gradually resumed its normal state of activity.

Two facts recorded by Mr. Neilson in connection with this outbreak are worthy of notice. 1st. The earthquake which accompanied the first great eruption on the 10th, and was felt so severely at Port Resolution, was not felt at all 12 miles away. 2nd. That on the same day as the eruption on Tana, a violent hurricane was raging at Efate 100 miles to the north, which island is on the direct line which passes through the various foci of volcanic activity in the group.

April 1888.—Intelligence arrived recently of another outbreak of volcanic force on Tana, during April of the present year. Full particulars are not yet to hand, but it appears that the eruption was again accompanied by an earthquake and further upheaval of the western shore of Port Resolution, which fine harbour is now reported to be destroyed, nothing larger than a boat being able to gain admittance.

So far as could be observed from the sea, no great change had occurred in the appearance of the volcano itself, which in June had again resumed its normal quiescent state.

Somewhere about the same time, the volcano on Ambrim also burst forth with great violence, and a great hurricane was raging in the north of the group; whether these three events were synchronous or not, I cannot say.

Having now placed before you all the particulars regarding this volcano available at the present time, I wish to draw your attention to certain conclusions which may, I think, be naturally based upon the facts already recorded. These conclusions refer to the position of the present focus of activity, the depth at which the explosions causing the eruptions take place, and the connection between the phase of eruption and the state of the weather.

On examining the plan of the district, it will be seen that the present focus of activity is at the extremity of the area affected by volcanic heat and pressure, the whole region between it and the sea appears to have been raised at a comparatively recent date, and has no connection with the main island, which is of a different geological formation. It would also appear probable, from the nature of the deposits, that either Port Resolution itself has been at one time an immense crater, or that there has been one about its entrance, The bed of twisted lava on the eastern outside coast-line would appear to strengthen this idea, as it is difficult to believe that it could have flowed from the present position of the volcano, with Port Resolution intervening in a direct line between.

It may I think also be concluded, from a comparison of the two beds of lava, the one referred to and the other close to the present cone, that the internal heat at Tana is diminishing. It may reasonably be assumed that the lava flow near Mount Yasur is the most recent, and this from the way in which it stands piled up presents the appearance of having issued forth in a much more viscous state than that on the outer coast-line.

With regard to the depth below the surface at which the force causing the eruption is generated, two circumstances will assist in determining this approximately. The first is the accompanying earthquake, the second the area of surface upheaved in the violent shocks. Every eruption is attended by an earthquake, which varies in force precisely as the eruption varies in magnitude, and they occur always at the same instant; these earthquakes are confined to the volcanic district, the most severe ever felt, that of 1878, not being noticeable 12 miles away. The origin, therefore, could not have been deep-seated, it being very evident that the deeper the origin, the more widespread and uniform would be the result. In the absence of accurate data as to the direction, the angle of emergence, and the relative force at different distances from the centre, no precise estimate can be made. The depth of the focus of an earthquake which shook the whole of Italy was fixed by Mr. Mallet as being about six or seven miles. The origin of the Tana earthquakes and eruptions must therefore be very much less than this. The fact also of the area upheaved or bulged upwards during the eruptions of 1878 and afterwards, being so small, would appear to strengthen the view that the origin of the disturbance is not deep-seated, for it is quite impossible to conceive of a small portion a few hundred yards in extent being lifted, the land around remaining *in situ*, without bringing the generating force very close indeed.

The connection of volcanic eruptions with the atmospheric pressure has frequently, and especially in late years, received attention, without however establishing it as a matter of fact. This no doubt is due to the incompleteness of the observations, and to the fact that only in connection with such volcanoes as Stromboli, and that on Tana, where the eruptions are so frequent, is it possible to take a sufficient number of observations to be of any value in this matter.

Professor Judd, the latest writer on this subject, referring to Stromboli, says :—"Whether the popular idea, that

the outbursts of Stromboli are regulated by atmospheric conditions has any foundation, is still open to grave doubt. It seems to be certain, however, that during the autumn and winter the more violent paroxysms of the volcano occur, and that in summer the action which takes place is far more equable and regular." This means, I take it, that during that portion of the year exposed to the greatest fluctuations of atmospheric pressure, the volcano exhibits the greatest variety in the phases of its eruptions.

That the Tana volcano is affected in this way, is open to very little doubt at all.

Almost every visitor from Captain Cook onward has noticed and recorded this fact. I had personally the opportunity of observing the eruptions during all kinds of weather, and the increase in their rapidity and force was invariable when the weather became unsettled, stormy weather approached, on the fall of rain and for a short time after rain. The most violent eruptions have always occurred during the summer, that is the hurricane months; in the winter when the trade winds are blowing, and day after day the weather does not vary, the eruptions are very regular and comparatively feeble. Mr. Neilson after an experience of its habits for 14 years reports in the same terms.

Although a series of accurate observations of the eruptions taken in connection with those of a barometer would be of great value in throwing light on this subject, the general law of the connection of the condition of the atmosphere and the nature of the eruptions may be considered as established, so far as this volcano is concerned.

It would be impossible to study the working of this remarkable engine of nature for any length of time without being led to consider the cause of it all, the reason of its regularity and of its irregularities, and the various peculiarities attending it. The inquiry is full of interest but beset with difficulties, so that theories must be advanced and received with caution in the limited state of our present knowledge.

I will, however, conclude this paper with an attempt to account for the varied and remarkable performances of the volcano under discussion.

The generally accepted theory of volcanic action is that it is due to three causes :—1st. The existence of molten lava beneath the surface of the earth's crust; 2nd. The percolation

of water upon these heated layers; 3rd. The escape through fissures or vents of high pressure steam, caused by the contact of the water with the molten lava.

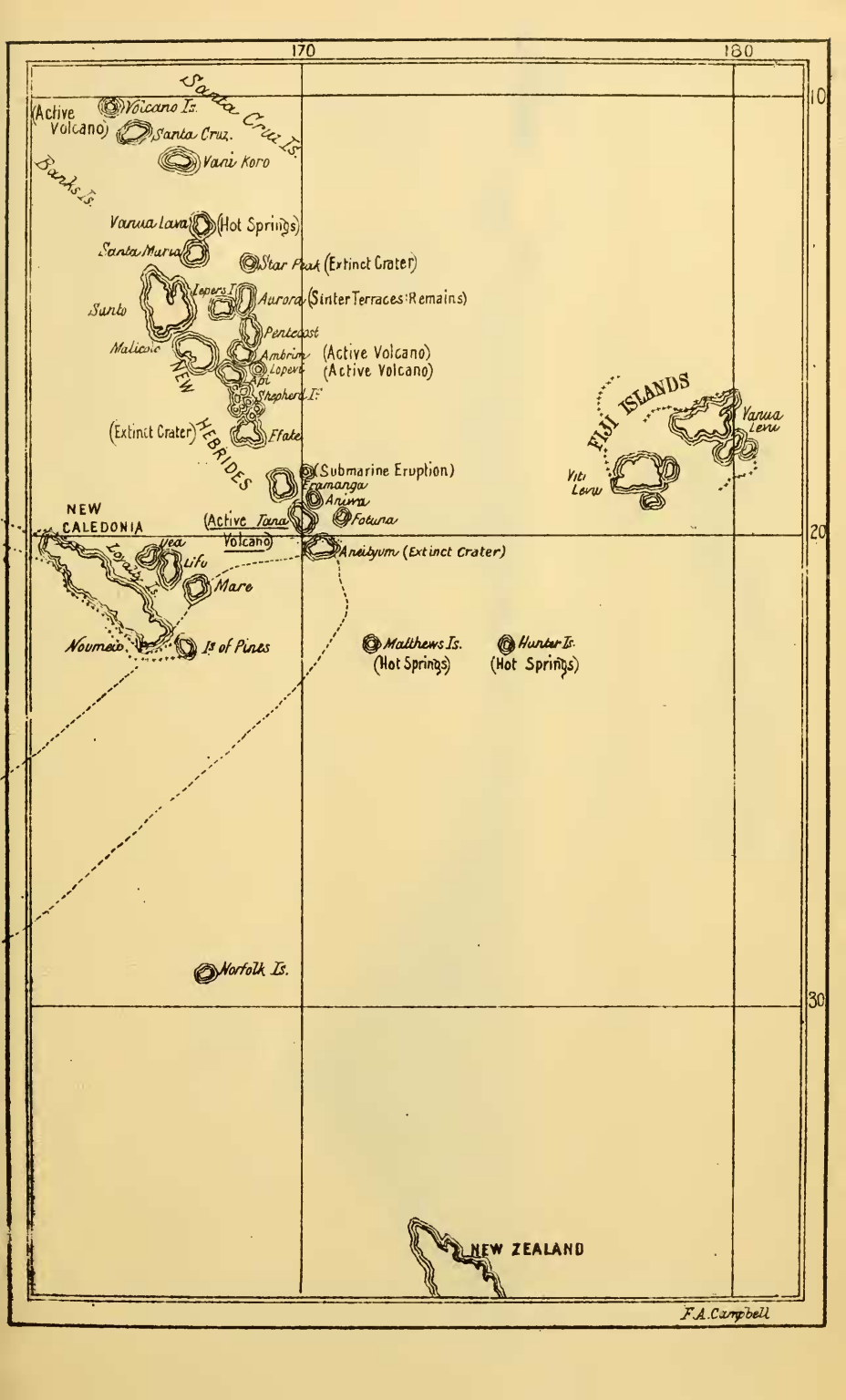
Professor Judd considers that the immediate cause of eruptions is due to the escape of high pressure steam through the lava, in the form of bubbles which rise and burst at or near the surface, much as would be the case if porridge were to be boiled in a tube. Now this does not appear to satisfy the conditions required for explaining the various phases of the eruptions of Mount Yasur, particularly the normal quiescent regular state.

With the aid of a diagram (plate 8), let me suggest another method, or it might be called a modification of the above.

I look upon the Tana volcano as a lava geyser or a natural underground steam machine, depending for its peculiarities upon the nature of the arrangements of the water supply, steam chamber, and outlet vent. I assume a lake of molten lava (F), which at normal atmospheric pressure maintains in the vent (C) a column at about a constant level. (D) is a space above the lava, filled with steam. The vent is tapped at a point below that at which the lava stands by a cave or fissure (B), into which the water supply from the lake (A) finds its way. This water coming into contact with the heated lava is turned into steam, which on the pressure becoming sufficiently strong to overcome the resistance, is forced under the column in the vent and ejects it with great violence. On the escape of the steam, the lava rises again immediately to its former level in the vent, and the steam making process goes on as before. The heat, the atmospheric pressure, and the water supply being constant, there is no reason why this process should not go on for ever with the most perfect regularity.

I may state that I have tested this arrangement practically, and have succeeded in obtaining the result as stated above, *i.e.*, a perfectly regular spasmodic ejection of fluid from a pipe by the steady admission of steam at a point below its surface.

As the molten lava would also contain steam at considerable pressure, or water ready to turn to steam, absorbed from the ocean, the effect of the escape up the vent of a considerable volume of free steam, and the emptying of what I have called the steam chamber, would be to cause a sudden decrease of pressure and an additional quantity of steam to be formed which would aid in the ejection of the lava.


170
180
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Santa Cruz Is.
(Active Volcano)
Volcano Is.
Santa Cruz.
Vani Koro
Banks Is.
Vanua Lava
(Hot Springs)
Santa Maria
Star Peak (Extinct Crater)
Sunta
Lopevi I.
Aurora (Sinter Terraces: Remains)
Pentecost
Malicolo
NEW
Ambrim (Active Volcano)
Lopevi (Active Volcano)
Epi
Shepherd I.
(Extinct Crater)
HEBRIDES
Ffate
(Submarine Eruption)
Tamanga
Aniwa
Fotuna
NEW CALEDONIA
(Active Volcano)
Tana
Aneityum (Extinct Crater)
Lea
Lifu
Loyalty Is.
Mare
Noumea
Is of Pines
Malthews Is.
(Hot Springs)
Hunter Is.
(Hot Springs)
FIJI ISLANDS
Vanua Levu
Viti Levu
Norfolk Is.
NEW ZEALAND
F.A. Campbell